

# Proton and kaon timelike form factors from BABAR

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The latest BABAR results on the proton and kaon timelike form factors (FF) are presented. The special emphasize is made on comparison of the spacelike and timelike FFs and the rise of the proton FF near threshold. The behavior of the cross section of  $e^+e^-$  annihilation into hadrons near the nucleon-antinucleon threshold is discussed.

## 1 Introduction

The cross sections of the  $e^+e^-$  annihilation into hadrons are described in terms of the electromagnetic form factors (FF). In case of production of proton-antiproton pair

$$e^+e^- \rightarrow p\bar{p} \quad (1)$$

the cross section depends on two such functions, electric ( $G_E$ ) and magnetic ( $G_M$ ) FFs:

$$\sigma_{p\bar{p}}(s) = \frac{4\pi\alpha^2\beta C}{3s} \left[ |G_M(s)|^2 + \frac{1}{2\tau} |G_E(s)|^2 \right] \quad (2)$$

where  $s$  is the  $e^+e^-$  center-of-mass (c.m.) energy squared,  $\beta = \sqrt{1 - 4m_B^2/s}$ ,  $C$  is the Coulomb interaction factor [ $C = y/(1 - e^{-y})$  with  $y = \pi\alpha(1 + \beta^2)/\beta$  for protons, and  $C = 1$  for neutrons],  $\tau = s/4m_B^2$ .

From the measurement of the total cross section the linear combination of squared form factors

$$F(s)^2 = \frac{2\tau |G_M(s)|^2 + |G_E(s)|^2}{2\tau + 1} \quad (3)$$

can be determined. The function  $F(s)$  is called the effective form factor. It is this function that is measured in most of experiments.

In case of production of kaons pair

$$e^+e^- \rightarrow K^+K^- \quad (4)$$

the expression for the cross section has the following form:

$$\sigma_{K\bar{K}}(s) = \frac{\pi\alpha^2\beta^3}{3s} |F_K(s)|^2 \quad (5)$$

There are many models describing timelike (TL) FFs, but definite predictions exist only for asymptotic region  $s \rightarrow \infty$ :

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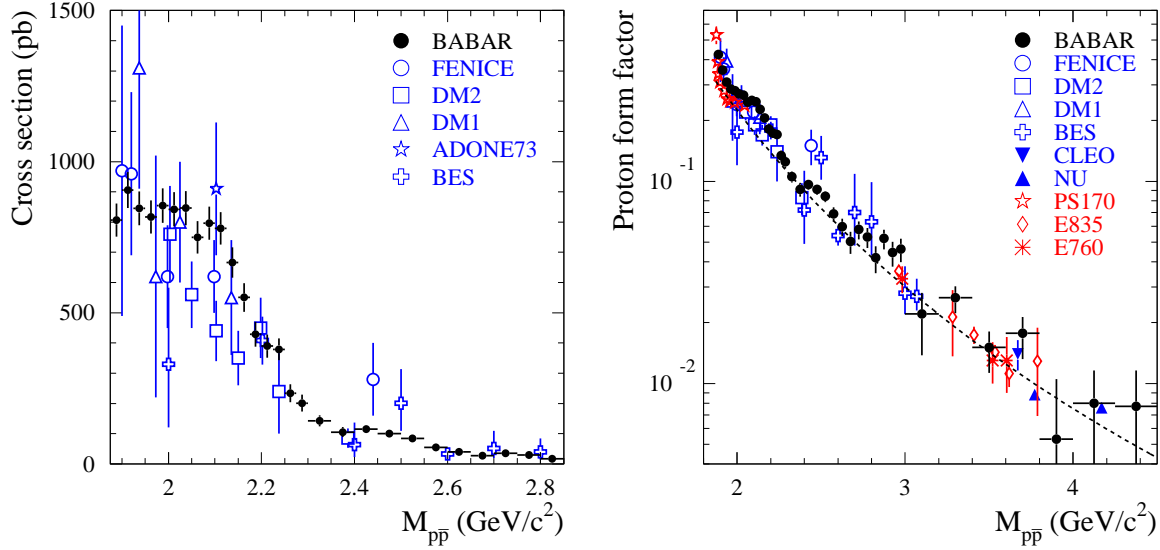


Figure 1: (Color online) **Left:** The  $e^+e^- \rightarrow p\bar{p}$  cross section near threshold measured by BABAR [1] and in other experiments. **Right:** The proton effective form factor [Eq.3] measured by BABAR [1] and in other experiments. The curve is the QCD motivated fit [Eq.6].

$$G_{E,M}(s) = G_{E,M}(-s) \sim \alpha_s^2(s)/s^2, \quad (6)$$

$$F_K(s) = (8\pi f_K^2 \alpha_s(s))/s \quad (7)$$

where  $\alpha_s \sim 1/\ln(s/\Lambda^2)$  is the strong coupling constant,  $f_K=156$  MeV is the  $K \rightarrow l\nu$  decay constant.

In the BABAR experiment the initial state radiation (ISR) method was developed and used to measure  $e^+e^- \rightarrow$  hadrons cross sections at energies lower than the collider (c.m.) energy. In this talk the latest results on the proton and charged kaon TL FFs from BABAR are presented.

## 2 The proton form factor

There are two BABAR experiments [1,2] on the proton FF, which use different ISR techniques. In the first method called large angle (LA) ISR, the ISR photon and proton-antiproton pair is required to be detected. LA ISR is effective at lower masses  $m_{p\bar{p}} < 4$  GeV/c<sup>2</sup>. The cross section for the process (1) measured using LA ISR in the near threshold region [1] is shown in Fig.1 (left). It slowly varies from the threshold up to 2.1 GeV/c<sup>2</sup> and then sharply goes down from 0.85 to 0.1 nb. Such a behaviour of the cross section can be explained by the final state nucleon-antinucleon interaction [3]. The proton FF value is close to 0.5 at the threshold (Fig.1 (right)). Then it decreases by two orders of magnitude up to 4.5 GeV/c<sup>2</sup>. Some deviations from the  $s^{-2}$  fit seen at 2.15 GeV/c<sup>2</sup> and 2.9 GeV/c<sup>2</sup> can be understood as contributions of  $p\bar{\Delta}(1232)$  and  $N(1520)\bar{N}(1520)$  intermediate states respectively.

In the second BABAR measurement of the proton FF, the ISR photon is required to be emitted at small angles (SA ISR) and undetected. The SA ISR is effective in the  $p\bar{p}$  mass range above 3 GeV/c<sup>2</sup>.

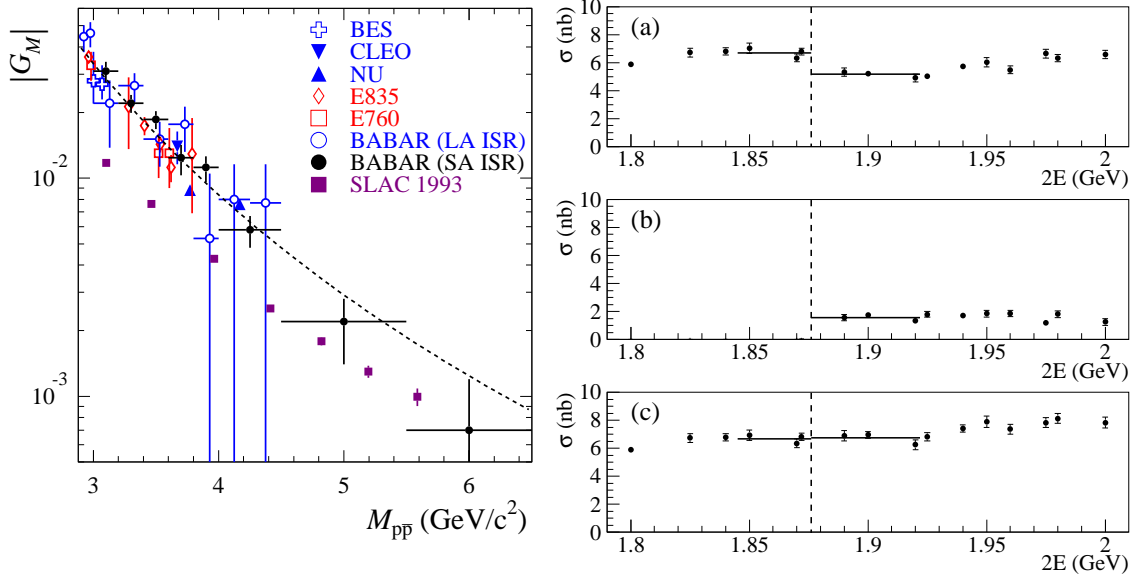


Figure 2: (Color online) **Left:** The proton magnetic form factor measured by BABAR [2] and in other experiments. The curve is the QCD fit. The SLAC 1993 points are the spacelike form factor data from  $ep$  scattering experiment. **Right:** The cross sections near nucleon-antinucleon threshold [5] for  $e^+e^- \rightarrow 6\pi$  (a), for  $e^+e^- \rightarrow p\bar{p}, n\bar{n}$  (b), and for the sum of  $p\bar{p}, n\bar{n}$  and  $6\pi$  processes (c).

The proton FF measured by BABAR using the SA ISR [2] is shown in Fig.2 (left). For comparison, the spacelike (SL) proton FF data are shown. The TL and SL FFs should be equal in the asymptotic limit. Below 4  $\text{GeV}/c^2$  the TL values are higher than the SL values by two times (Fig.2 (left)). But beginning from 5  $\text{GeV}/c^2$  the tendency of approaching TL data to SL data is seen.

As it seen in the Fig.1 (left) the  $e^+e^- \rightarrow p\bar{p}$  cross section, measured by BABAR, has a step-like shape with a step height of about 0.85 nb. The similar behaviour is observed for the  $e^+e^- \rightarrow n\bar{n}$  cross section [4]. The sum of these cross sections shown in Fig.2 (right,b) has the step height near 1.7 nb. One can expect that such a step must be compensated by a similar negative step in the meson production cross section. It was noticed in the work [5] that such 1.7 nb negative step is observed in the  $e^+e^- \rightarrow 6\pi$  cross section. So, the total cross section (sum of  $e^+e^- \rightarrow 6\pi$  and  $e^+e^- \rightarrow p\bar{p}, n\bar{n}$ ) has no structure (Fig.2 (right,c)). Today there is no clear understanding, why only the  $e^+e^- \rightarrow 6\pi$  process is sufficient to compensate the nucleon-antinucleon step.

### 3 The charged kaon form factor

Similar to the proton FF, the charged kaon TL FF was measured at BABAR with LA and SA ISR techniques, allowing to study different  $K^+K^-$  mass ranges. In the first LA measurement [6] the  $K^+K^-$  mass range was studied from threshold up to 5  $\text{GeV}/c^2$ . This is the most precise measurement of the  $e^+e^- \rightarrow K^+K^-$  process below 2.6  $\text{GeV}/c^2$ . The obtained FF values (Fig.3 (left)) are about 4-5 times higher than the asymptotic QCD prediction.

In the second kaon FF measurement [7] using the SA ISR technique, the  $K^+K^-$  mass range was extended up to 7.5  $\text{GeV}/c^2$ . The measured scaled kaon FF ( $M_{K^+K^-}^2 - F_K$ ) in the range 2.6-7.5  $\text{GeV}/c^2$  is shown in Fig.3

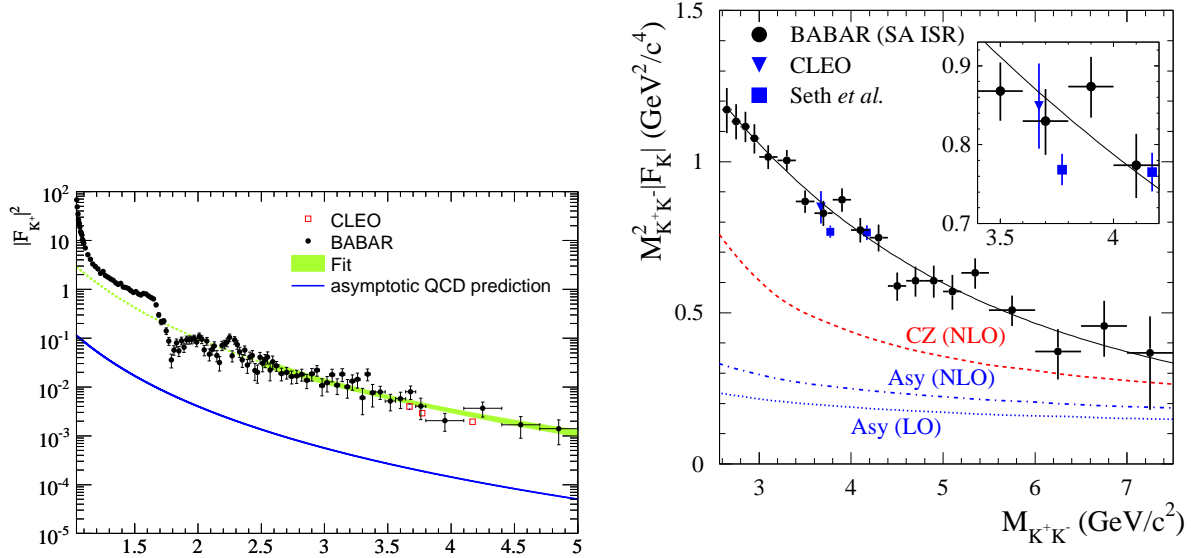


Figure 3: (Color online) **Left:** The charged kaon form factor versus  $M_{K^+K^-}$  ( $\text{GeV}/c^2$ ) measured by BABAR [6]. **Right:** The scaled charged kaon form factor measured by BABAR [7]. Different QCD based predictions are shown by the curves lying below data points. The region near  $\Psi(3770)$  is shown in the inset.

(right). The QCD model prediction from different authors are shown by the curves lying below the experimental points. The references for these predictions can be found in the original BABAR paper [7]. One can see in Fig.3 (right) that beginning from 6  $\text{GeV}/c^2$  the BABAR experimental point errors begin to intersect the QCD prediction. The main conclusion from these data is that the kaon FF begins to approach to the QCD asymptotic limit when energy increases.

## 4 Summary and Outlook

In recent years, thanks to development of ISR technique at BABAR, a great progress has been achieved in the experimental study of TL electromagnetic FFs of charged hadrons. In this talk new data are presented for proton and charged kaon FF. A comparison with the QCD predictions is made. It was found that at energy higher than 5  $\text{GeV}$  for proton and 6  $\text{GeV}$  for the charged kaon the measured FF values begin to approach to their asymptotic QCD limit.

**Acknowledgment.** The author expresses his gratitude to V.P. Druzhinin for fruitful discussion. This work is partially supported in the framework of the State order of the Russian Ministry of Science and Education and the RFBR grants No. 15-02-01037 and Sci.School 2479.2014.2.

## References

- [1] J. P. Lees et al., (BaBar Collaboration), *Phys. Rev. D* **87**, 092005 (2013)
- [2] J. P. Lees et al., (BaBar Collaboration), *Phys. Rev. D* **88**, 072009 (2013)

- [3] V. F. Dmitriev, A. I. Milstein and S. G. Salnikov, *Phys. Atom. Nucl.* **77**, 1173 (2014)
- [4] M. N. Achasov *et al.*, *Phys. Rev. D*, **90**, 112007 (2014)
- [5] A. E. Obrazovsky, S. I. Serednyakov, *JETP Letters* **89**, 315 (2014)
- [6] J. P. Lees *et al.*, (BaBar Collaboration), *Phys. Rev. D* **88**, 032013 (2013)
- [7] J. P. Lees *et al.*, (BaBar Collaboration), arXiv:1507.04638v1 [hep-ex] (2015)